Design of Microstereolithography System Based on Dynamic Image Projection for Fabrication of Three-Dimensional Microstructures

Jae Won Choi, Young Myoung Ha
Department of Mechanical and Intelligent Systems Engineering, Pusan National University,
San 30 Jangjeon-dong, Geumjeong-gu, Busan 609-735, Korea

Seok Hee Lee*
School of Mechanical Engineering, Pusan National University,
San 30 Jangjeon-dong, Geumjeong-gu, Busan 609-735, Korea

Kyung Hyun Choi
Department of Mechatronics Engineering, Cheju National University,
Jejudaehakno, Jeju-si, Jeju-do 690-756, Korea

As demands for complex microstructures with high aspect ratios have increased, the existing methods, MEMS and LIGA, have had difficulties coping with the number of masks and fabricable heights. A microstereolithography technology can meet these demands because it has no need of masks and is capable of fabricating high aspect ratio microstructures. In this technology, 3D part is fabricated by stacking layers, 2D sections, which are sliced from STL file, and the Dynamic Image Projection process enables the resin surface to be cured by a dynamic image generated with DMD™ (Digital Micromirror Device) and one irradiation. In this paper, we address optical design process for implementing this microstereolithography system that takes the light path based on DMD operation and image-formation on the resin surface using an optical design program into consideration. To verify the performance of this implemented microstereolithography system, complex 3D microstructures with high aspect ratios were fabricated.

Key Words: Microstereolithography, Microstructures, Digital Micromirror Device (DMD), Curing

1. Introduction

Nowadays demands for ultra-precise parts such as micro-mechanical parts, information and communication devices, and medical devices are increasing. MEMS and LIGA technology have met these demands for a long time, but they have technical limitations when fabricating complex 3D parts or devices with high aspect ratios. Microstereolithography technology has been studied and developed to overcome these limitations, although it has weakness about fabricable material in comparison with MEMS and LIGA. The microstereolithography process is most similar to the conventional stereolithography process and uses the same input format, STL. A final part is fabricated by slicing a modeling part, generating a machining path, and stacking each fabricated layer sequentially. There are two types of microstereolithography system, scanning and projection, that can be used in curing method (Varadan et al., 2001).

In scanning method as shown in Fig. 1, the part
is produced by stacking each fabricated layer using focused beam spot control on the resin surface according to the sliced section shape. The X-Y stage is usually used for scanning the focused beam spot, and the Z stage is used for stacking the fabricated layers. In 1993, Ikuta and Hirowatari (1993) reported the development of the first type of microstereolithography called Integrated Harden polymer process (IH process) and this system have been continuously upgraded (Ikuta et al., 1996; 1998; 1999). The fabrication resolution is almost several μm wide and deep. The latest system that was developed is called a two-photon IH process that uses two-photon absorption and can usually fabricate microstructures with resolution of hundreds nm in the μm range (Maruo et al., 2003; Park et al., 2005; 2006). Using similar scanning microstereolithography systems, unique microstructures have been fabricated and a variety of investigations have been conducted by several researchers around the world (Zhang et al., 1999; Sun and Zhang, 2002; Lee et al., 2004; Kim et al., 2005).

In projection method shown in Fig. 2, the part is produced by stacking fabricated layers using a technique similar to the scanning type. However, each layer is cured by dynamic mask and one irradiation from light source at a time. The Z stage is only used for stacking the fabricated layers. Projection microstereolithography can produce microstructures faster than the scanning type because it requires little time to scan with its focused beam spot. To make a dynamic pattern, LCD (Liquid Crystal Display) and DMD (Digital Micromirror Device) are used. In the mid 1990’s, a projection microstereolithography system using LCD was first developed (Bertsch et al., 1997). An electric signal enables each pixel to be opened and closed on the LCD according to the desired pattern. This LCD projection microstereolithography system has been improved and is capable of producing a variety of microstructures with resolutions of several μm wide and deep (Farsari et al., 2000; Provin and Monneret, 2002; Oda et al., 2004). In the beginning the system’s resolution was low because of the contrast produced by the LCD, but current systems have higher resolution due to improvements to LCD. DMD has been used in place of LCD as dynamic pattern generator due to its high contrast and resolution (Bertsch et al., 2000; Smith, 2004; Bertsch et al., 2004; Limaye, 2004; Sun et al., 2005; Choi et al., 2005). Each pixel on the DMD reflects incident light according to desired bitmap image. The resolution of the DMD microstereolithography system is a few μm and better than that of the LCD microstereolithography system. Especially, Sun et al. (2005) have been produced suspended beam with 600 nm diameter, which is the smallest feature among the reported projection based microstereolithography processes.

Above reported papers pass over optically designing and verifying the system for the reliability, though they employ a few resolutions and can fabricate microstructures. In this paper, we address the optical design process for implementing microstereolithography system by taking the light path based on the DMD operation and the focused image on the resin surface using an optical design program into consideration. The optical